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ABSTRACT

This paper examines intersections between mathematical and language performance in light of data collected from Hispanic students at varying stages of acquiring English as a second language at school. Emphasis is on aspects of the developing linguistic system as it affects underlying metacognitive processes related to mathematical performance. Sections of the report consider metacognition and bilingual learners; cognitive/academic language proficiency (CAL) and cognitive, analytic, mathematical proficiency (CAMP) intersections; the language of mathematics and metacognition; and the learning of mathematics in terms of person, task, strategy, and the regulation of cognition. Finally, implications for mathematics education are presented. Illustrations of behaviors of learners from primary grades to adults are interspersed. (MNS)

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MATHEMATICS AND LANGUAGE INTERSECTIONS FOR HISPANIC BILINGUAL STUDENTS

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MATHEMATICS AND LANGUAGE INTERSECTIONS FOR HISPANIC BILINGUAL STUDENTS

Although the processes and content of mathematical inquiry share much that is universal, they intersect with language-specific contexts in ways that can profoundly affect mathematical performance. Because mathematics achievement generally shows a significant positive correlation with verbal ability (Cocking & Chipmam, 1983), we may argue that successful mathematical performance depends, at least in part, on proficiency in the language of instruction. This has particularly strong implications for the mathematics education of limited English proficiency (LEP) Hispanic bilingual students.

This paper examines intersections between mathematical and language performance in light of data collected from Hispanic students at varying stages of acquiring English as a second language (ESL) at school. Emphasis is on aspects of the developing linguistic system as it affects underlying metacognitive processes related to mathematical performance. These interrelationships may be observed for minority students at all ages - grade 1 through adult - engaged in the processes of becoming bilingual at school.

In a model developed by Burton (1984), the dynamics propelling mathematical thinking stem from two levels: cognitive and affective. The cognitive level includes manipulating elements such as physical objects, visuo-spatial imagery, symbols, ideas and sensing patterns and relationships as well as their verbal and non-verbal articulations. Affectively, processes are propelled by curiosity, surprise, or the need to resolve a cognitive conflict. To examine intersections between mathematics and language, we may distinguish verbal components from

other cognitive factors in these dynamics. We may then take the position that the interaction of cognitive, linguistic, and affective experiences guides development of mathematical inquiry and learning.

METACOGNITION AND BILINGUAL LEARNERS

Building on and refining Polya's (1957) model, Garofalo and Lester (1985) distinguish cognition in doing mathematics from metacognition. The latter involves knowledge of cognition, choosing and planning what to do, and regulation of cognition, monitoring what is being done.

Flavell (1981) describes metacognitive knowledge with a set of categories which Garofalo and Lester (1985) apply to mathematical performance: (1) person knowledge, (2) mathematical task knowledge, (3) mathematical strategy knowledge.

Person knowledge includes assessment of one's own ability in mathematics, either in general or in reference to specific tasks. It also includes effects of affective variables such as motivation and anxiety and, for language minority students, beliefs or assessments about doing mathematics in a second language (L2). Task knowledge includes beliefs about mathematics and the nature of specific tasks, including an awareness of the effects of linguistic features on task difficulty. The knowledge needed to perform specific tasks can be severely constrained by inadequate language proficiency. The third variable, metacognitive strategy knowledge, includes both knowledge of strategies and awareness of their usefulness for specific tasks. Knowledge of algorithms and heuristics and strategies for comprehending and solving problems, often language-based, are part of strategic

knowledge. Because person, task, and strategy intersect with language, evidence of these intersections with the developing language systems of L2 learners can provide insights into the mathematical achievement of language minority students..

For the regulation of cognition, monitoring strategies include processes such as using prior knowledge, rereading, and drawing inferences. For the L2 learner, strategies intersect with ability to process textual discourse and to draw on knowledge gained through prior schooling or through socio-cultural contexts. We may expect prior knowledge, particularly as it relates to the student's culture, to have direct bearing on the language minority student's mathematical achievement.

Both metacognitive knowledge and metacognitive regulatory behaviors link directly to the cognitive and affective dynamics of mathematical inquiry. In so doing, they incorporate crucial connections with language in mathematical performance. Connections between metacognition and language provide, then, a framework by which we can examine more closely the intersections between mathematics and language for linguistic minority students.

CALP AND CAMP INTERSECTIONS

In a model applicable to explaining what is involved in knowing language for mathematical performance, Cummins (1984) conceptualizes language proficiency along two continuums. One relates to the extent of contextual support available to the language user and the other to the degree of cognitive demands imposed by specific tasks. Language

proficiency relying extensively on paralinguistic and situational cues to meaning in face-to-face, cognitively undemanding discourse is differentiated from that depending essentially on linguistic or literacy-related cues to meaning in cognitively demanding tasks. The latter is often referred to as cognitive/academic language proficiency, CALP. School success requires proficiency in CALP.

Acquiring a second language for school use, including mathematics, imposes high cognitive demands. Using language as a cognitive instrument requires taking meaning from the printed page without other cues. It also involves processes for writing clearly and accurately. The ability to use CALP as an instrument of thought increases in importance with progression through the schooling process. If we take the position that the intersections between mathematics and language hold a central position in mathematics achievement, the role of CALP in L2 becomes crucial for the successful performance of minority students.

In line with Cummins' notions of language proficiency, Dawe (1984) proposes a model for mathematical proficiency. He distinguishes surface fluency in basic individual mathematical skills from cognitive, analytic, mathematical proficiency (CAMP). It is the ability to reason efficiently with the abstract deep structure of mathematics. CAMP relates verbal-analytic, symbolic, rational thought typical of left brain processes with non-verbal, analogic, visuo-spatial, intuitive, non-rational thought associated with right brain activities. Although it has its own identity, particularly as it relates to right-brain functions, CAMP intersects with CALP to define the language of mathematics.

THE LANGUAGE OF MATHEMATICS AND METACOGNITION

The language of mathematics is a subcomponent of CALP in many respects. It is a written, context-reduced language requiring cognitively demanding tasks. It uses signs or symbols, formulas, and equations intended to be read. Only the most elementary mathematical expressions can be fully communicated orally (Dawe, 1984). Mathematical reasoning requires integration of CAMP with linguistic features of CALP.

Mathematical meanings with the linguistic modifications used in expressing those meanings define a mathematics register as identified by Halliday (1975). Others (Crandall, Dale, Rhodes & Spanos, 1985; Kessler, Quinn & Hayes, 1985; Cuevas, McClung & Mann, 1985; Cuevas, 1984; Dawe, 1984) have followed Halliday's characterization of the register to expand and refine it, particularly in terms of the linguistic problems that the language of mathematics poses for ESL learners.

Linguistic problems with the mathematics register fall under three major categories: (1) vocabulary, (2) syntax, (3) discourse. To illustrate how problems in the language of mathematics may impinge on metacognition, data used here is from intact classrooms in which Hispanic students are at various age, grade, and ESL proficiency levels. We look first at language intersections with the metacognitive knowledge variables of person, task, and strategy. We then examine aspects of language associated with the regulation or monitoring of cognition.

PERSON AND THE LANGUAGE OF MATHEMATICS

To investigate person knowledge or assessment of one's own abilities for mathematical tasks, LEP students were asked to write what they found hardest and easiest in doing mathematics in L2. Responses give insights into affective variables driving mathematical performance.

A grade 3 student responded that the hardest part is 'grafs because Some times I don't no What I should realy do'. The easiest part is 'word problems because I like to do them very much and plus because I no the anseres.' One third grader wrote that 'tines is the hardest in math.' Another, however, found 'large problems on multiply' (multiplication with large numbers) the easiest. A fourth grader commented, 'The hard thing in math the tables' and 'The easy thing in math is Division.'

Adult ESL learners reflect the increasing demands of the language system. One commented 'The easiest thing for me is doing simple math, like +, x, -, % etc.' In contrast, 'The hardest thing in doing math in English is understand the meaning of words that the instructions give.' Another makes similar observations in writing 'The most easy in the problemen is if it is present graphic.' For that student 'The most difficult for me in a problemen is can't traslate the words and can't understand the problemen.' Still another wrote, 'is hardest because I no understand some words that are very important to solve write problems. Is easiest because I know the means of the numbers write such as 30 - 2 = 28'. These students were aware of the language problem in mathematics.

Beliefs about what is hardest or easiest can potentially affect, either positively or negatively, the dynamics driving mathematical performance

. For the older ESL learner, language knowledge may more strongly shape beliefs and attitudes about mathematics than for younger students. Clearly, the individual variation present in these personal assessments has implications for the mathematics teacher working with ESL learners.

TASK AND THE LANGUAGE OF MATHEMATICS

Mathematical task knowledge is knowing the scope and requirements of tasks. This intersects with L2 knowledge of the lexicon, syntax, and discourse rules.

Lexical Knowledge

Vocabulary knowledge for mathematical tasks has at least four distinct dimensions: (1) specific terms unique to mathematics, (2) the labels attached to mathematical symbols, (3) lexical items marked with unique meaning for the mathematics register, (4) collocations of words to express mathematical notions.

An example of difficulties with specific terms is seen in the exchange between an adult ESL learner and teacher on the meaning of the term quotient:

> Student: What's this q-u-o-t-i-e-n-t? (spells the word)
>
> Teacher: Math term for an answer in division.
>
> Student: Thought I knew what to do, but when I saw that quotient, I just stopped. Guess I ran out of English.

Asked to complete grade-appropriate worksheets, a sixth grader could not attach meaning to specific terms such as denominator, factor, exponent, equation, perimeter. Later, as a result of the ESL teacher's

help, the student completed the activity sheets with 100 percent accuracy.

Learning to relate terms and symbols presents its own set of difficulties. Asked to circle appropriate symbols for a set of terms, a grade 4 child indicated a multiplication product by circling the = sign in the mathematical statement 6 x 7 = 42. Another circled 21 as the quotient in 21 ÷ 3 = 7 and 4 as the dividend in 20 ÷ 4 = 5. Over 60 percent of third grade LEP students could not give word equivalents for the 'greater than' and 'less than' symbols.

The unique meanings of ordinary words in a mathematics context also present difficulties. As an example, a third grader followed the directions 'Make a table' as used in mathematics by drawing a picture of a table as used in the home. In an adult class of 10, no student knew the word 'times' in its meaning of 'multiplied by'.

To further illustrate lexical problems, a grade 1 student could not add new meaning to the word 'second'. For this student 'second' had only one meaning, one that fused the cardinal number 'two' with the ordinal 'second'. To complete a worksheet on 'time', the following exchange took place between the teacher and LEP student:

Teacher: What is the blue thing going around the clock.

Student: (no response)

Teacher: the second hand

Student: (puzzled) clock have two hand

'Second' was being presented as one thing, 'the blue thing', in the context of unit of time. Distinctions between 'second' as a measure of time and as an ordinal number were simply not yet part of that LEP

student's lexicon. This student had not yet identified differences between 'second' and 'two' much less 'time unit'.

A problem with lexical collocations is evident in a grade 4 student's difficulty with 'square feet'. Unable to resolve semantic conflicts between the notions of 'square' and 'feet', this student missed the mathematical notion of 'square feet'.

As Richards (1985) outlines, lexical knowledge implies knowing the constraints of function and situation on word choice such as the use of 'table' or 'square feet' in mathematics discourse. It also includes knowing the network of word associations such as 'product and multiplication'. Furthermore, knowing a base form and its derivations makes it possible to relate 'divide', 'division', 'divisor', 'dividend'.

In examining factors affecting academic achievement in a second language, Saville-Troike (1984) found that knowledge of vocabulary is the most important linguistic component when learning academic content through a second language. Although many vocabulary problems are not unique to the ESL student, they present serious barriers to mathematics achievement and to the LEP student's successful competition with native speakers of English.

Syntactic Knowledge

Syntax presents at least three major sources of difficulty: (1) word-symbol correspondence for mathematical statements, (2) syntactic structures typically utilized in setting up mathematical problems, (3) extensive use of logical connectors linking propositions.

An illustration of word-symbol correspondence is seen in an adult ESL student's interpretation of 5 x 4 = 20 as 'five time four to twenty'. Inappropriate use of the preposition 'to' in this expression could potentially confound multiplication statements with ratio statements which utilize the preposition to. Another adult expressed 3 x 5 = 15 as 'tree plus five equal five'. Failure to distinguish the symbol x from + obviously directs the wrong task applications.

Another adult learner interpreted 6 < 10 as 'six small ten' and 14 > 3 as 'fourteen big three'. Variations in syntactic expressions of 4 > 2 varied from 'four is major two', 'four higher than two' to 'four minor two'. Similar data was found with young children at all levels.

A fourth grader expressed 2 + 2 = 4 as 'two add two seem four' where substitution of 'equals' with 'seem' gives a different semantic notion. In another grade 4 class, students were asked to verbalize the problem:

$$3\overline{)\,9}\qquad 3$$

Of the 16 LEP children in the class, 15 wrote 'three divide(d) by nine equal(s) three. In a class of 10 adult ESL students, only 2 could verbalize 10 ÷ 2 = 5 with the expression 'divided by'.

Syntax interfaces with semantics in the structure of questions frequently found in mathematics problems. On a grade 2 subtraction worksheet, questions guiding this task varied from 'How many were there in all?', 'How many were there then?', 'How many more were there?', 'How many were left?', 'How many fewer were there?'. Syntactic

variation on a single semantic notion can present serious language problems for the L2 learner.

A syntactic device used to mark relationships between two or more structures is that of logical connectors. Words or phrases such as and, or, if...then, because, consequently, however serve a semantic, cohesive function, indicating the nature of the relationship between the parts of a text. Mathematics texts typically include signals for addition or similarity, contradition, cause/effect or reason/result, and chronological or logical sequence (Celce-Murcia and Larsen-Freeman, 1983).

In a study contrasting the use of logical connectors by LEP children at grade 6 with those at grade 8, Tritch (1984) found evidence for a developmental sequence, with younger learners making more errors than older ones. Research evidence (Dawe, 1983) indicates that logical connectors are critical to the development of mathematical reasoning in English as a second language.

It is, of course, difficult to separate the linguistic structure from the mathematical task in many instances. In one adult class, 50 percent of the ESL students missed the question, 'Which is greater, 1/2 or 1/3? It is not clear if the problem is with the syntax signalled by the logical connector 'or' asking for a comparison or with the concepts in the fractions.

Discourse Knowledge

Successful solution of mathematical word problems intersects with metacognitive task knowledge and linguistic knowledge in complex ways.

Reading comprehension is an integral part of solving word problems, a competency that overlaps with both CALP and CAMP. Word problems make use of context-reduced language. It is here that the characteristic lack of redundancy or paraphrasing in the mathematics register presents particular difficulties for the L2 student. Furthermore, discourse competence in mathematical thinking involves the functional use of language, particularly the representative function, or telling how things are, and the directive function, or requesting others to do things (Searle, 1976). Linguistic inability to handle lack of redundancy and to process representative and directive functions can have negative effects on task knowledge.

To illustrate discourse difficulties, a class of grade 4 LEP children was asked to do a multiplication problem using symbols only. The class scored 51% accuracy. But when the same problem was given as a word problem, the accuracy level dropped to 6%.

Word problems involve both language forms and functions. They require processing lexical and syntactic structures and appropriate interpretations of language functions. A class of second graders, for example, had difficulty interpreting the problem: 'Sue has 32 cards. She gave Jim 15 cards. How many cards did Sue have?' The majority answered 15 rather than the correct response 17. Students may not have recognized the representative function expressed in possessing 32 cards and giving 15 away or in the directive function requesting statement of the number of cards remaining. As a result, they missed the connections to metacognitive task knowledge for subtraction.

An adult class was asked to underline any words that made solving the following problem difficult:

> The regular price for five organ lessons is $78.00. Cymbals is having a special this week. They are giving 5 lessons for $66.50. How much money can you save on each lesson?

The word most consistently underlined was 'special'. Others had difficulty with 'save'. Only 1 of 11 students could solve the problem.

Solving word problems requires integration of linguistic and mathematical knowledge. CALP and CAMP, metacognition, and cognitive functioning intersect in ways as yet little understood in the mathematical performance of L2 learners.

STRATEGY AND THE LANGUAGE OF MATHEMATICS

Metacognitive strategy knowledge includes knowledge about algorithms, heuristics, and strategies to help with problem comprehension.

One strategy L2 learners use is to draw on knowledge about algorithms or heuristics without reference to linguistic knowledge. To illustrate, no LEP child in a second grade class understood the worksheet heading 'Vertical Addition' but all could do the addition task because of the presence of the + symbol. Similarly, none could explain the heading 'Three Addends' but all could solve the problems. They drew on a strategy in which + served as a signal to add.

A discourse exchange between the teacher and a first grader shows strategic knowledge.

> Teacher: (presenting a card showing 5 + 2)

What is the sum?

Student: 7

Teacher: What does 'sum' mean?

Student: 'a little bit'

Linguistically, the student did not understand the teacher's question but the problem appeared to call for addition. For another second grader 'sum' meant 'same'. The strategy this child used for addition was to give a number the same as one in the problem. A class of 7 adults was given the problem, 'Find the sum of the following numbers: 12, 15, 16. All answered '13, 14'. They too did not know the term 'sum'. Strategically, they drew on the linguistic clue, 'following', taking it to mean 'subsequent' or 'next'.

Even very young learners develop a strategy that utilizes graphics or illustrations and can, consequently, solve problems without reference to linguistic knowledge. A grade 1 worksheet illustrates these sentences: 'There are 5 fish in all. 2 are going away (in the same direction). 3 are left.' Students had no difficulty with subtraction but the teacher's questioning of children individually showed they did not know expressions 'in all', 'going away' or 'are left'.

A similar difficulty appeared in an addition problem showing 3 lions standing still and 2 lions running towards them. Grade 1 LEP students gave the correct answer '5' but none could give a meaning to the printed question, 'How many are there in all?' The strategy to rely on the drawings and ignore the verbal expression of the problem worked.

A strategy can fail, as it did for fourth-grader Jose who answered '14' for the following problem:

There were 8 (drawing of black cat)

There were 6 (drawing of white cat)

How many more (drawing of black cat) were there?

Jose explained to his teacher that 'more' means to add. Jose's inadequate language proficiency barred an understanding of the subtraction task in the question 'How many more were there?'

Use of graphic or symbolic cues is one part of metacognitive strategy available to L2 learners at all ages and proficiency levels. Linguistic strategies are utilized as language proficiency increases. Strategies of LEP students, however, do not assure success in mathematical performance.

Intersections of language with person, task, and strategy knowledge are influenced by language proficiency levels of the lexicon, syntax, and discourse. As a result, metacognitive knowledge and language proficiency together serve to influence decisions about strategies used in the regulatory behaviors of metacognition.

REGULATION OF COGNITION AND THE LANGUAGE OF MATHEMATICS

Although monitoring task understanding and regulating strategy can take a variety of forms, regulation of cognition is essential in the complex activity of problem-solving. Of particular relevance for the language minority learner is the role of prior knowledge or experience.

Prior knowledge can be viewed from three dimensions: knowledge of mathematics (CAMP); knowledge of language (CALP), including the CALP/CAMP intersection for the mathematics register; knowledge of real world settings in which mathematical problem-solving occurs. More

precisely, the socio-cultural context for problem-solving plays a critical role in regulatory strategies. If the learner has no familiarity with the content of the problem presented, if it requires experience beyond that offered through the learner's culture, the functioning of mathematical problem-solving strategies can be impaired.

Cross-cultural issues in mathematical problem solving are highly complex and beyond the scope of this paper. However, it is insightful to examine specific problems for the extent to which they demand prior experience in socio-cultural contexts beyond that of Hispanic minority students.

A fourth grader was unable to solve a grocery story problem about buying a 'box of Cheer'. Puzzled, he asked the teacher how 'cheer' could come in a box when his only experience with this lexical item was 'cheer at a soccer game'. Further discussion revealed that he had no experience with going to the supermarket. His mother did the grocery shopping when he was at school. Another student could not do a problem about scores in a game of bowling. His only semantic marking for 'bowl' was as a dish. With no knowledge of the sport, he had no strategy for solving the problem.

Grade 5 students could not solve a series of problems dealing with United States currency when given graphic representations of coins. They simply did not know a quarter from a penny. Problems which displayed an array of coins followed by questions on how much was spent to buy various items called for either addition or subtraction, mathematical processes within the students prior experience. However, these recently arrived students had no experience at that point with

the monetary system of their new surroundings. They could not determine 'costs' and 'money left'.

In a class of 11 adults, only 1 student could solve the following problem:

> Mary made $100 base salary and 15% extra on tips. How much money did she make in all?

Students expressed problems with 'base salary', 'extra on tips' along with the syntactic problem of 'make in all'.

Illustrative of the culture-boundness of many word problems in mathematics texts is the following from a high school Algebra II text:

> Suppose you go into business raising thoroughbreds and quarter horses. Having studied linear programming, you decide to maximize the feasible profit you can make. Let x be the number of thoroughbreds, and let y be the number of quarter horses you raise each year. Write inequalities expressing each of the following requirements...Draw a graph of the feasible region... (Foerster, 1984:p. 93)

Thoroughbreds and quarter horses, linear programming, and maximizing feasible profit all present notions beyond the experience of many minority students.

A secondary school student who had strong algebra background in his first language and who consistently performed well on problems presented in symbolic notation could not handle the extensively culture-bound word problems on applications of algebra and trigonometry functions found throughout the textbook from which this example is taken. However, once the mathematics teacher became sensitive to the problem, with the help of the ESL teacher, the student progressed

rapidly when applications were brought within range of the student's experience and language proficiency.

Failure to understand the problem-solving context inhibits analysis of the problem information along with other aspects of regulatory behavior: organizing and carrying out the plan, checking results.

IMPLICATIONS FOR MATHEMATICS EDUCATION

In summary, the processes and content of mathematics intersect with language in ways critical to mathematical achievement of language minority students. Without adequate language proficiency to support the cognitive and affective dynamics which propel cognitive processes in mathematical thinking, LEP students are disadvantaged in mathematical performance. Underlying the cognitive processes in doing mathematics are metacognitive aspects of knowledge of cognition and regulation of cognition. Knowledge factors of person, task, and strategy together with regulatory behaviors dependent on prior experience appear to interact directly with language proficiency. In other words, language proficiency has direct bearing on metacognition and the dynamics in the cognitive processes of mathematical reasoning.

Language intersects with person knowledge to affect attitudes and beliefs about mathematical performance. For example, viewing word problems as too hard to deal with because the language is not comprehensible serves to impede mathematical performance in a second language. Task knowledge is markedly constrained by language proficiency in all components of the mathematics register: lexicon, syntax, discourse. Metacognitive strategy knowledge incorporates the

L2 learner's knowledge of ways to compensate for not understanding the meaning of language used and to avoid language in mathematical operations. Metacognitive regulatory knowledge is, among other things, affected by the students background in mathematics and by the socio-cultural experiences the learner brings to the task.

Successful mathematical performance in a second language requires adequate levels of proficiency in the language of mathematics functioning within appropriate socio-cultural contexts. Under conditions which facilitate development of the metacognitive knowledge and behaviors needed for mathematical performance, Hispanic students acquiring ESL can concurrently develop mathematical reasoning and language proficiency. A curriculum which attends to knowledge structures and thinking processes with meaningful, relevant language input can utilize mathematics as a medium of language development and, simultaneously, language as a medium of development in mathematics. Many learners fail to reach their potential in academic achievement because their language learning is not well coordinated with their learning of school content or subject matter (Mohan, 1986). As Cummins (1986) argues, language use and development consciously integrated with school content in collaborative tasks can generate positive dynamics and empower minority students for school success.

Mathematics educators sensitive to the intersections between language and mathematics hold the potential to integrate metacognitive and linguistic development in communicative, socio-cognitive contexts. Understanding at least some of the complex set of relationships for successful mathematical performance as they apply to the large numbers

of Hispanic bilingual students currently in the schooling process is crucial for mathematics educators. Important for all students, the intersection of language with mathematics is a critical one for those not yet proficient in the linguistic medium of mathematical thinking. Mathematics educators sensitized to intersections between language and mathematics can contribute powerfully to the development of both mathematics and language for linguistic minority students.

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